Muon Collider Machine-Detector Interface: Recent Results and Plans

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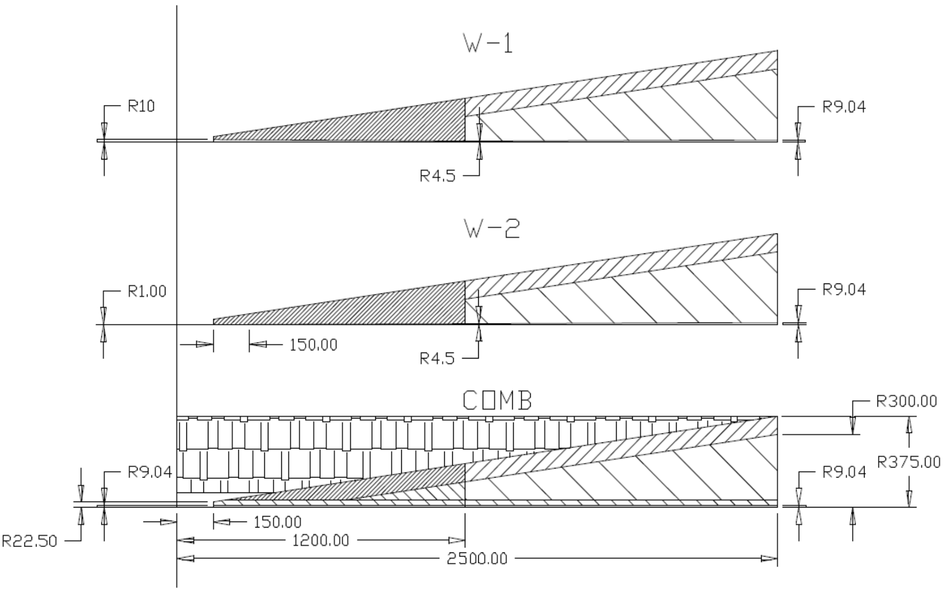
OUTLINE

- Background Sources (see my previous talk)
- Collimating Nozzle and Dipoles in IR
- MARS15 Modeling in IR and Detector, November 2009
- Background Loads in Detector
- IP versus Machine Backgrounds
- MARS15 Modeling and Magnet Design, January 2010
- MDI Issues and Work to Do

Collimating Nozzles at IP

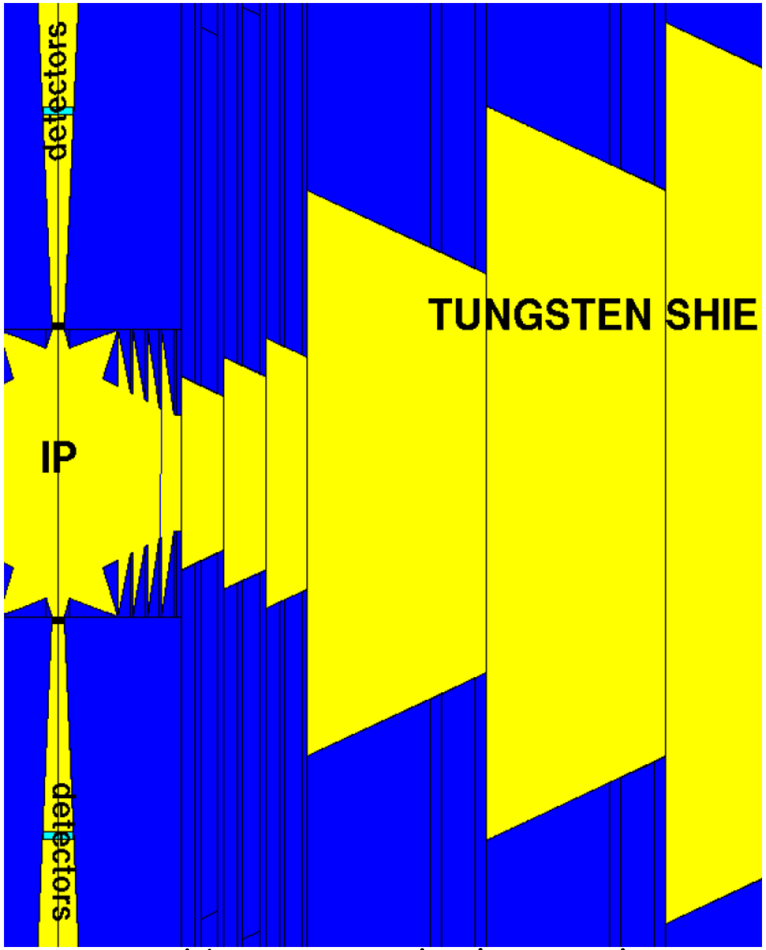
As was found, the most effective collimation includes a limiting aperture about one meter from the IP, with an interior conical surface which opens outward as it approaches the IP. These collimators have the aspect of two nozzles spraying electromagnetic fire at each other, with the charged component of the showers being confined radially by the solenoidal magnetic field and the photons from one nozzle being trapped (to whatever degree possible) by the conical opening in the opposing nozzle.

Nozzle Concepts



B. Foster & N. Mokhov (1994):
Background reduction 30 to 500 times

R=4cm



4m

Detector is not connected by a straight line with any surface hit by decay electrons in forward or backward directions (I. Stumer)

Spreading Decay Electrons Along IR

SC sweep dipoles with tungsten catchers between IR elements :
another factor of seven background reduction (Carol Johnstone and NM, 1996)

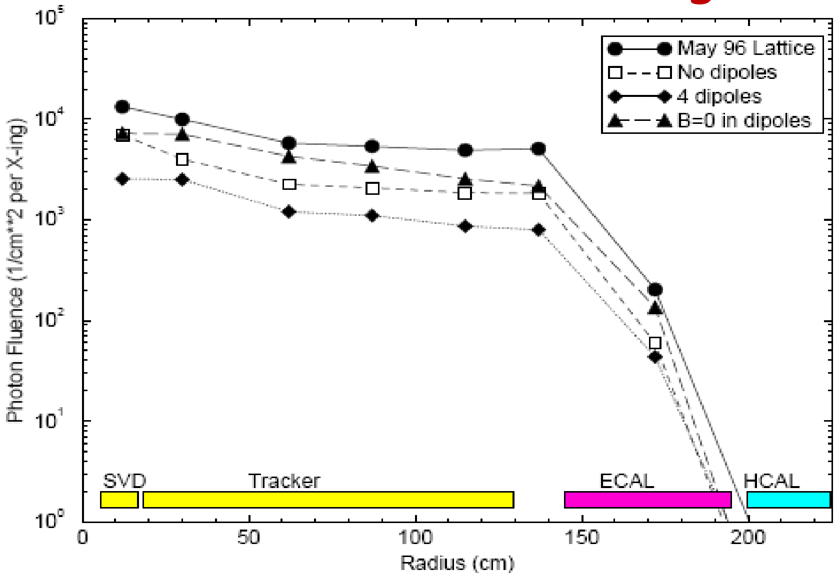


Figure 7: Radial dependence of photon fluence in the ± 1.2 m central detector region around the IP per 2×2 TeV $\mu^+\mu^-$ bunch crossing for different IR scenarios due to muon beam decays.

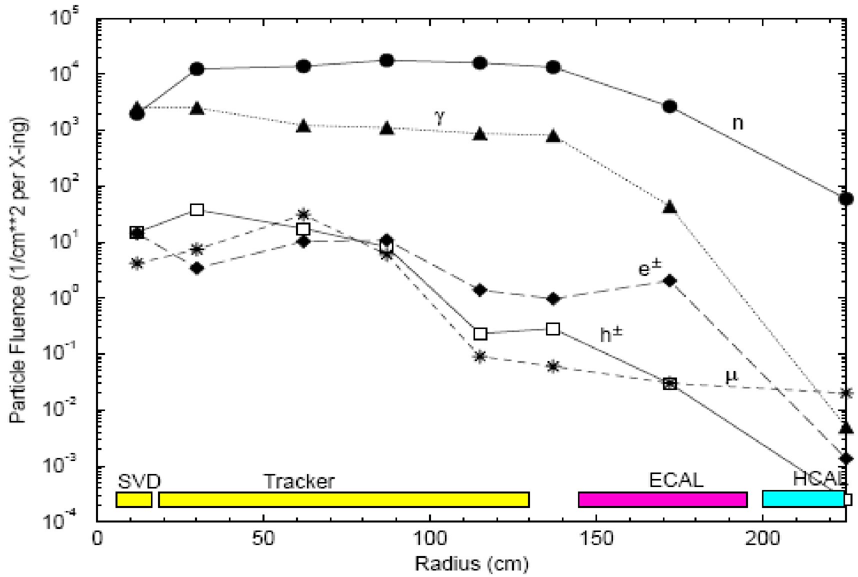
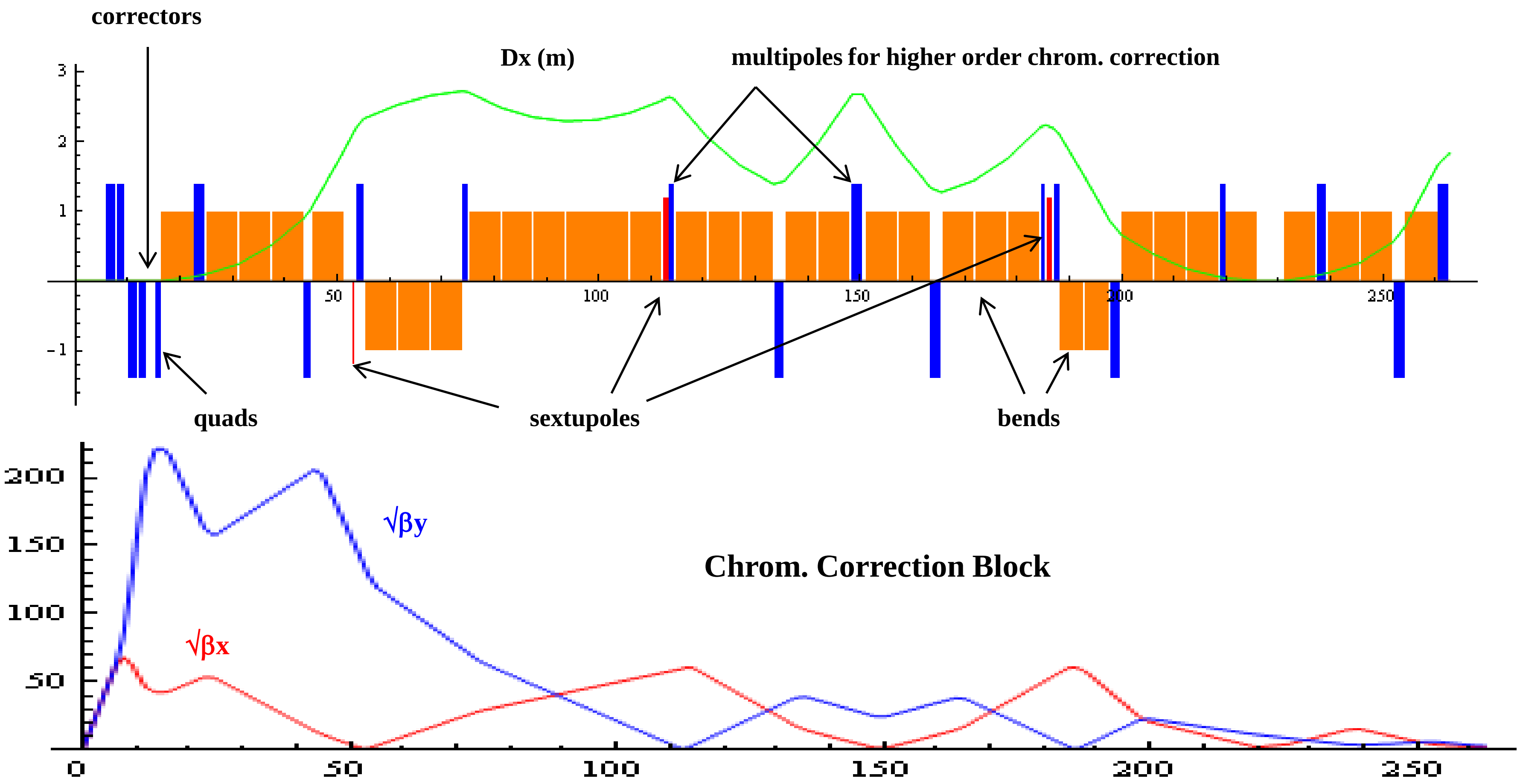


Figure 8: Radial dependence of particle fluence in the ± 1.2 m central detector region around the IP per 2×2 TeV $\mu^+\mu^-$ bunch crossing for the best IR configuration considered.

Helps suppress Bethe-Heitler muons which cause significant fluctuations in transverse energy and missing transverse energy due to energy spikes in deep inelastic interactions of such muons.

IR Design by E.Gianfelice-Wendt & Y.Alexahin (2009)



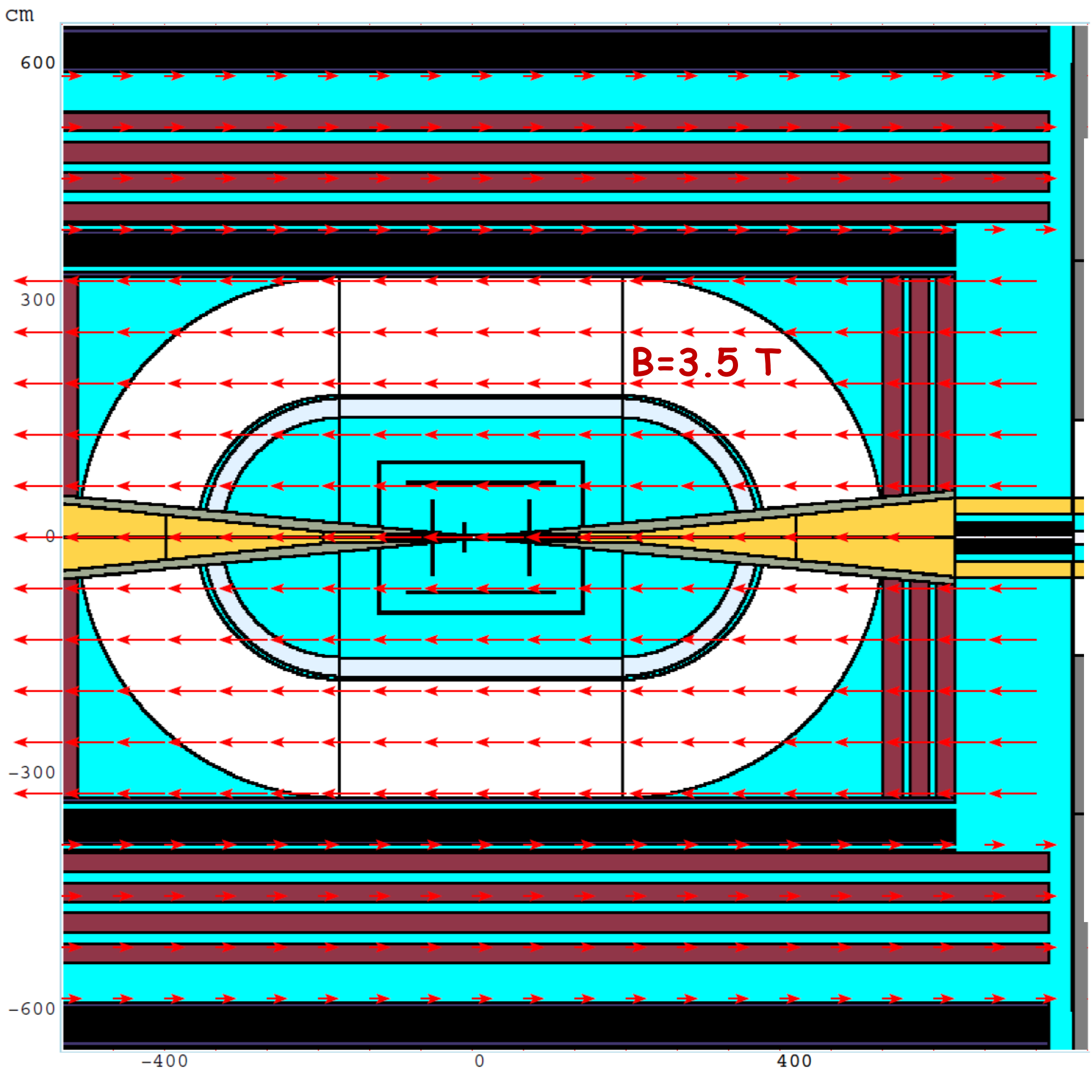
Tungsten Cone in BCH_2 Shell

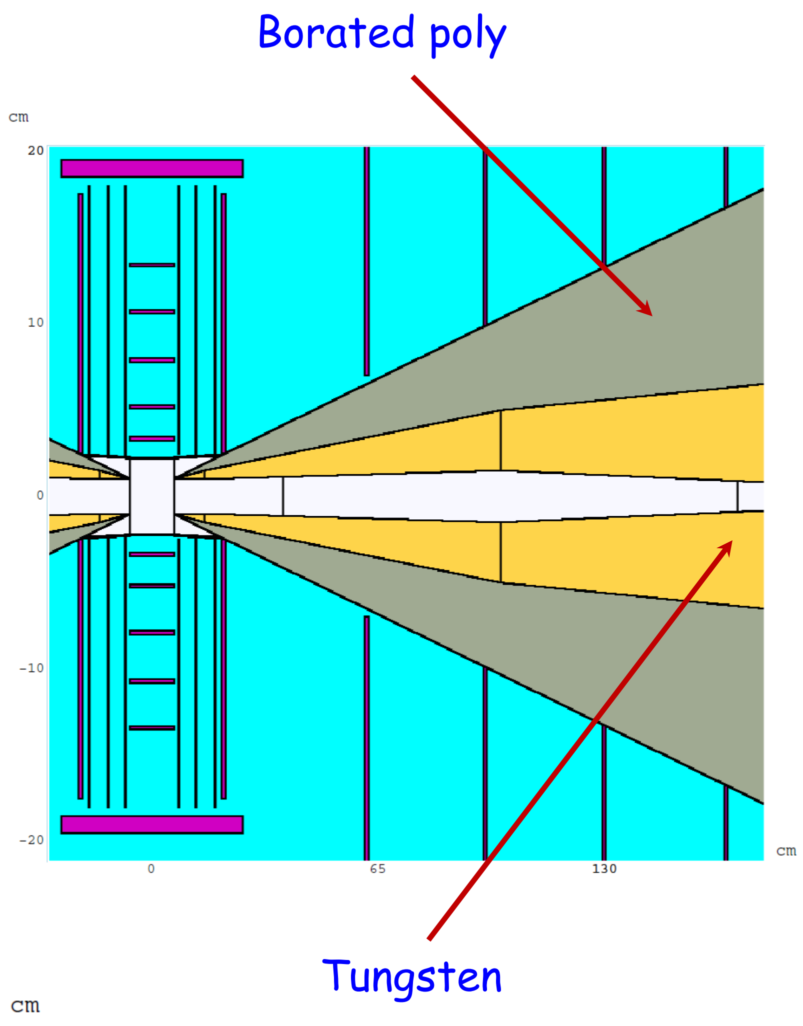
1. **<u>Minimize it</u>** as much as possible (20^0 to $6\text{-}9^0$) because of serious limitations on possible physics:
   - Top production in forward regions as CoM energy goes up
   - Asymmetries are more pronounced in forward regions
   - Z' => ttbar
   - Final states with many fermions (like ordinary SM tt events) are hardly ever contained in the central detector
2. **<u>Instrument it</u>**:
   - Forward calorimeter
   - Lumi-cal a'la ILC – 40-140 mrad for precise measurement of the integrated luminosity ($\Delta L/L \sim 10^{-3}$)
   - Beam-cal at smaller angles for beam diagnostics

MARS15 Modeling

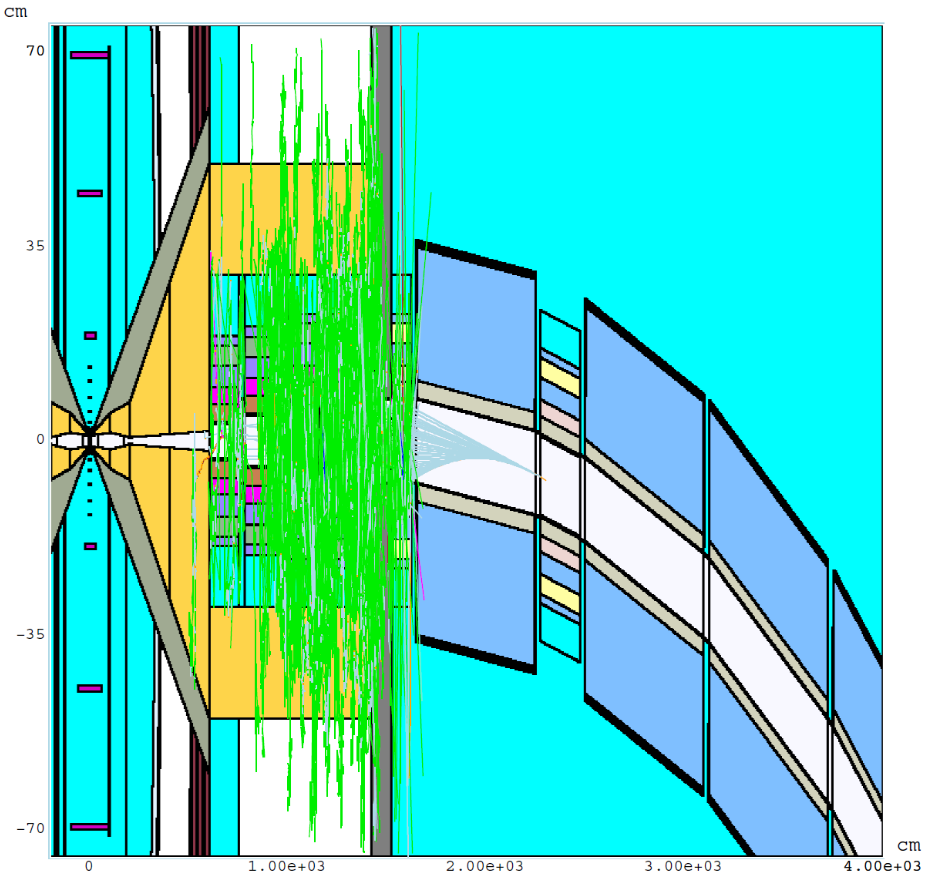
- 250-m segment of EGW-YA lattice implemented in MARS15 model in two versions, with $\cos\theta$ and open midplane dipoles.
- Model includes rather detailed magnet geometry, materials, magnetic fields (maps and simplified descriptions), tunnel, soil outside and a simplified experimental hall plugged with a concrete wall.
- It includes 4th concept ILC detector with B_z=3.5 T and tungsten nozzle in a BCH_2 shell (about 6° cone), starting at ±6cm from IP with R=1 cm at this z.
- 750-GeV bunch of 2×10^{12} μ^- approaching IP is forced to decay at -10 to 200 m at 4.28×10^5 per meter rate.
- Cutoff energy is optimized for materials & particle types, varying from 2 GeV at ≥100 m to 0.025 eV in the detector.

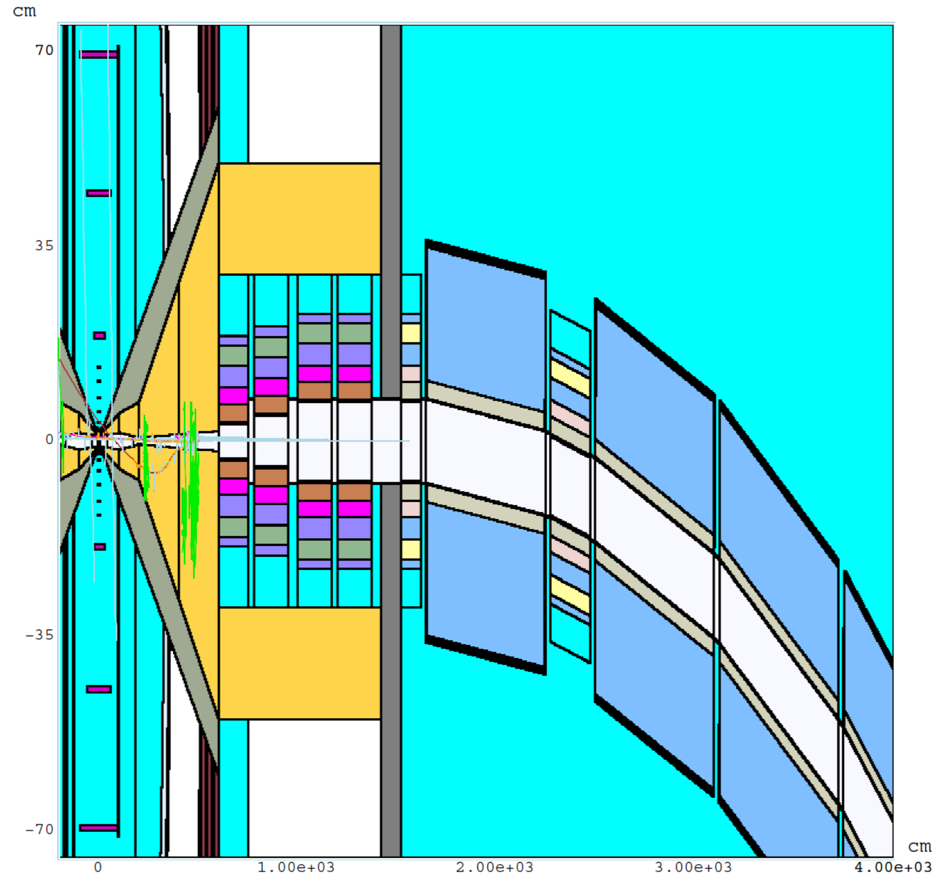
4th Concept Detector at MC: MARS15 Model



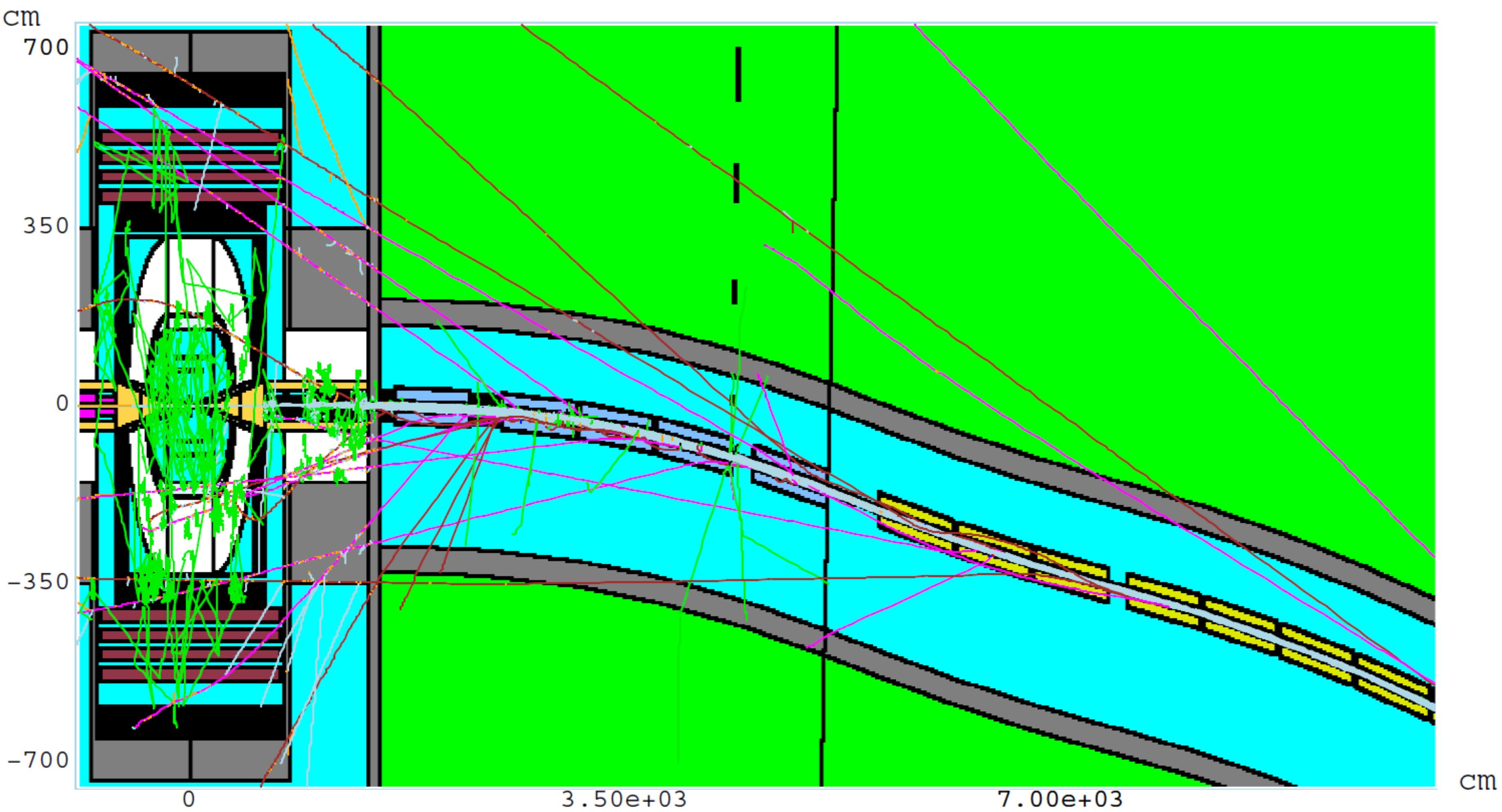


Two Decay Events

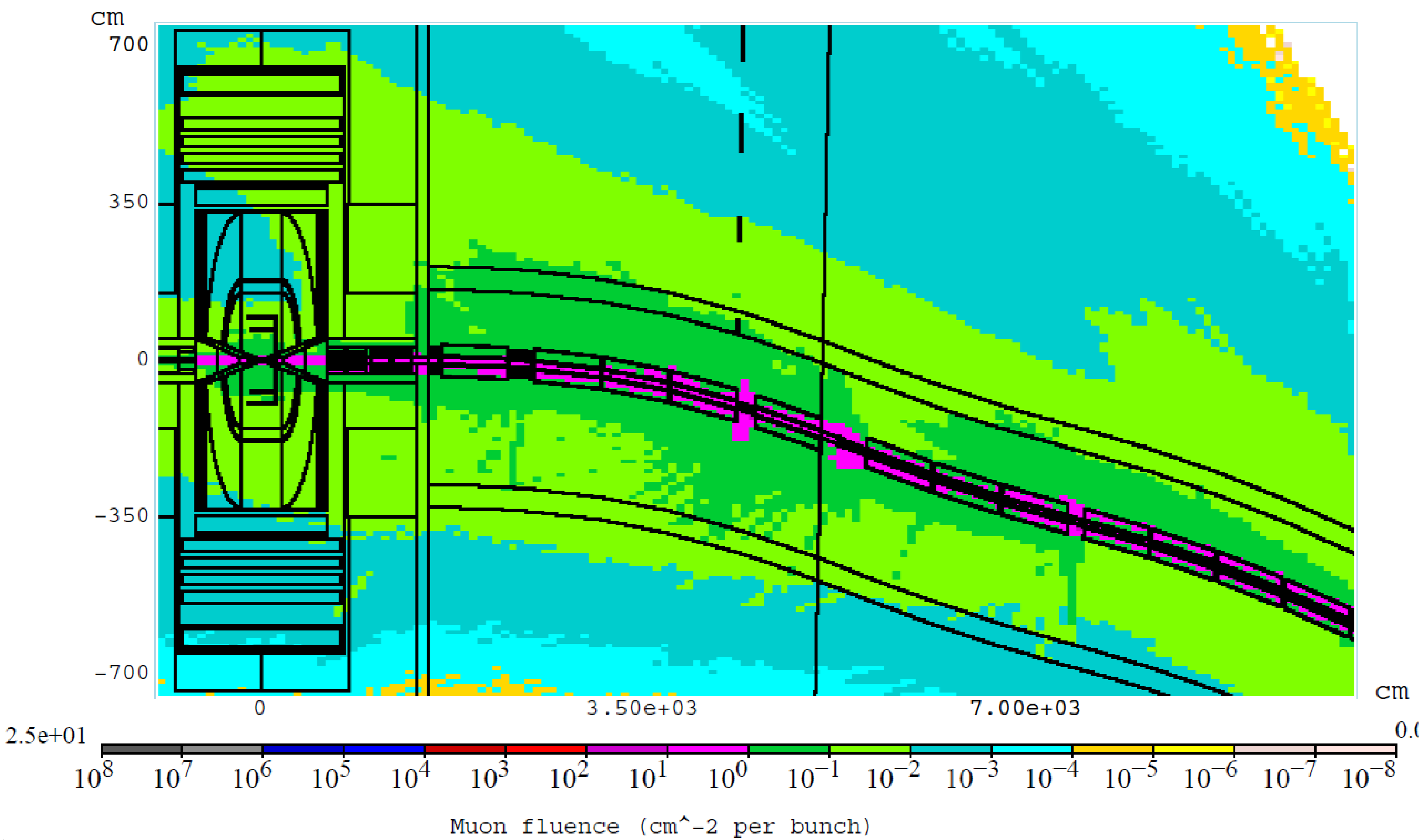




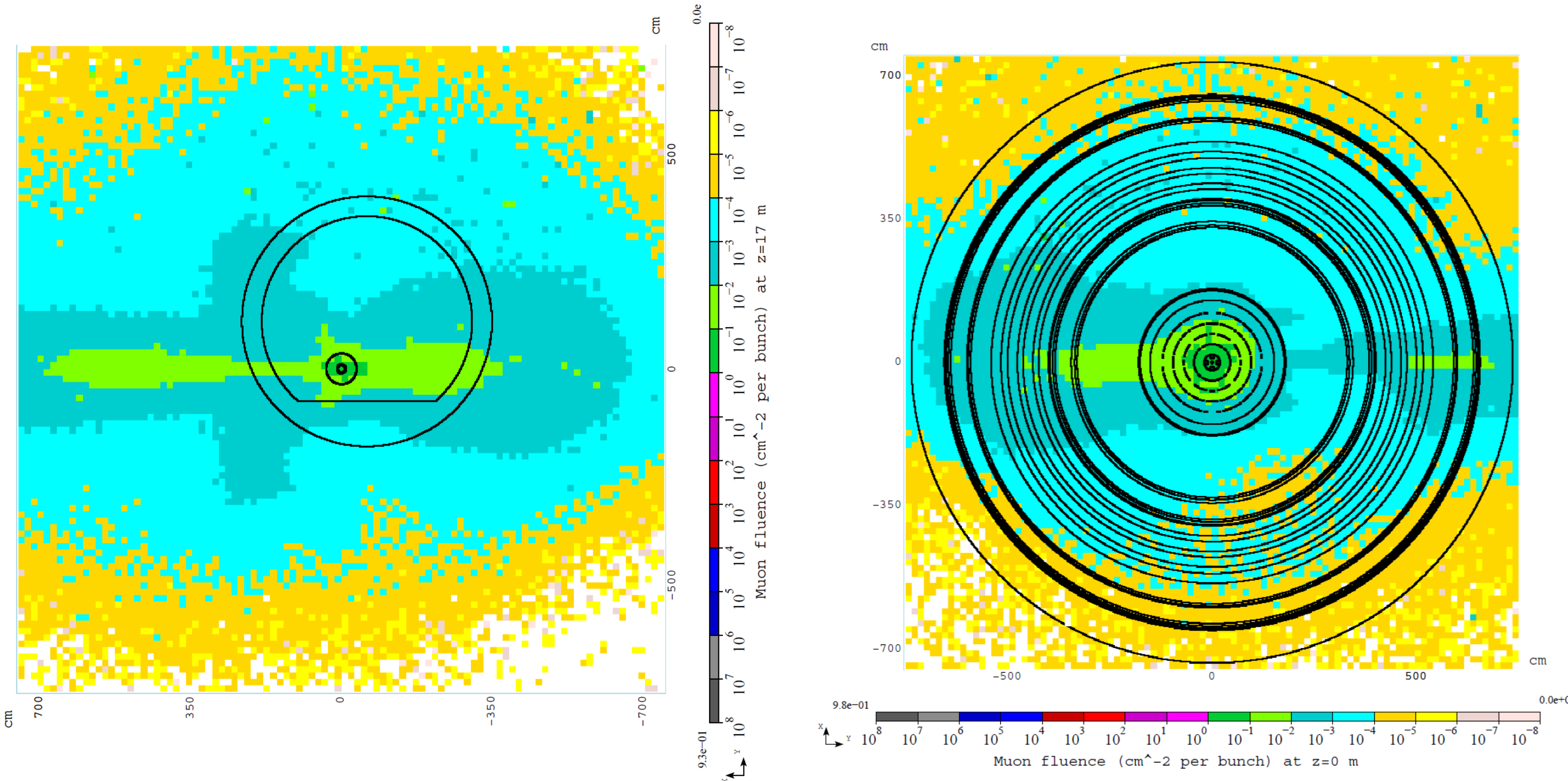
Tracks in IR



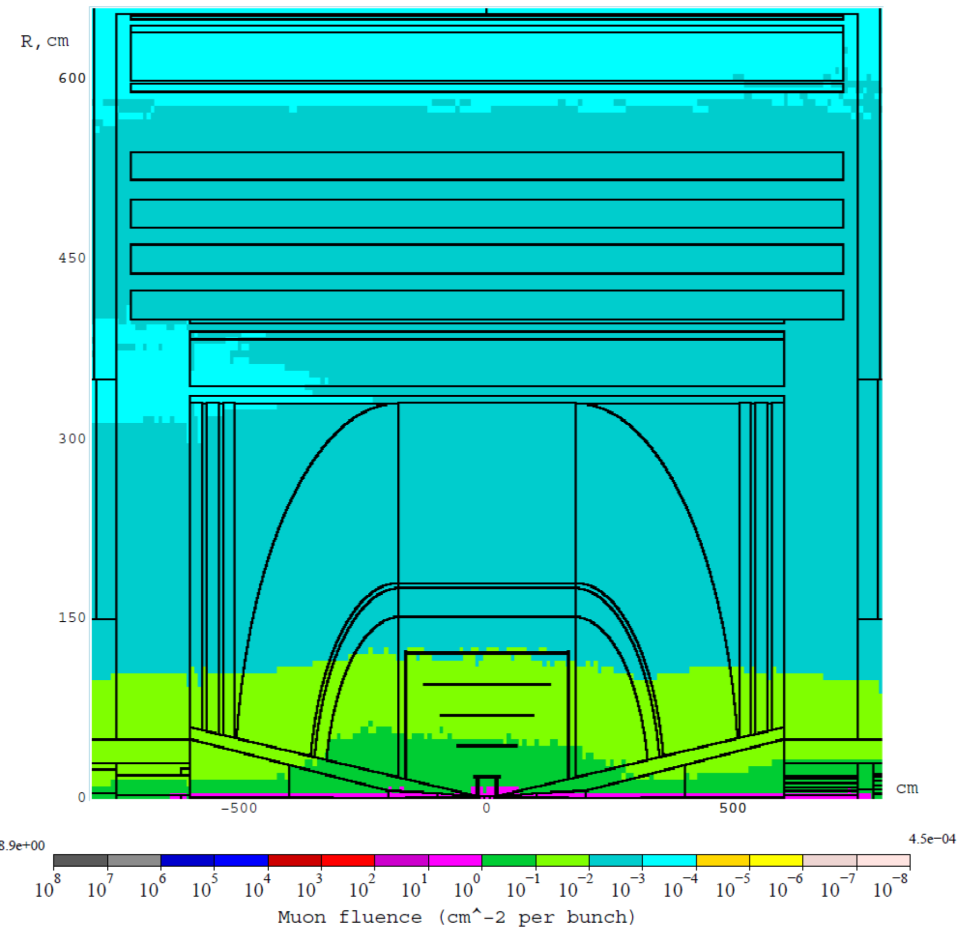
Muon Fluence in Orbit Plane

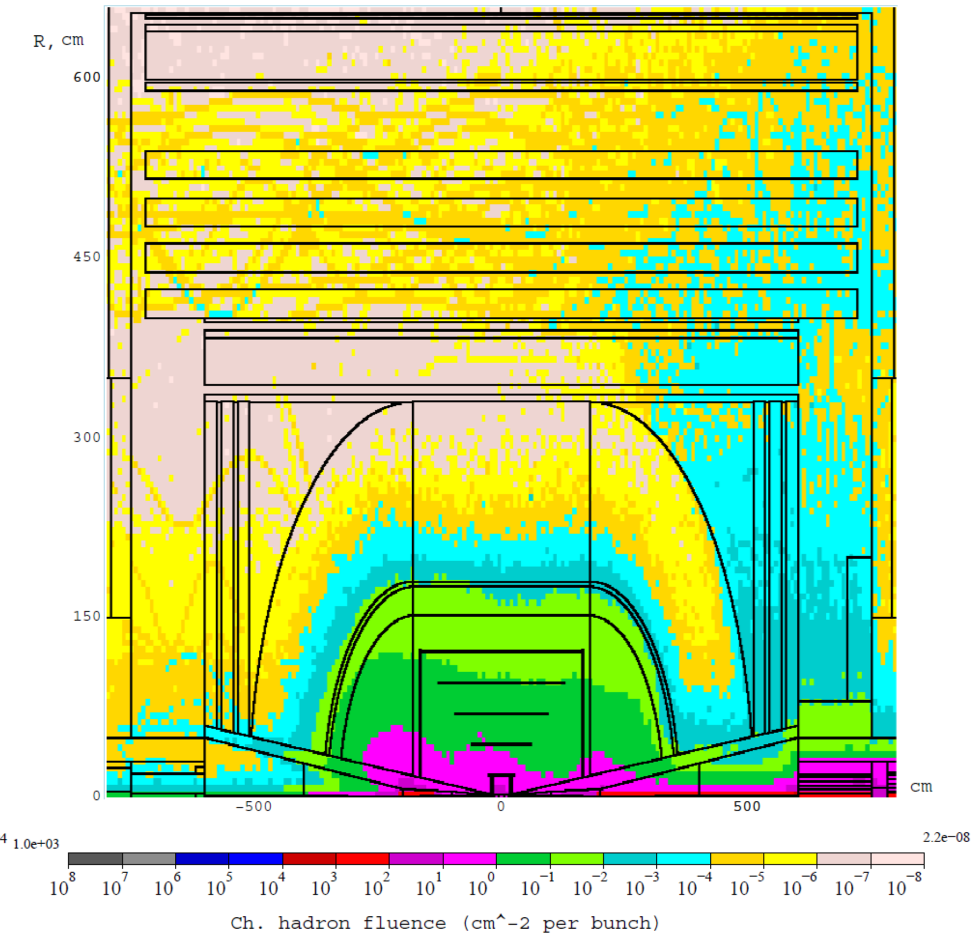


Muon Fluence at z=17 m and z=0

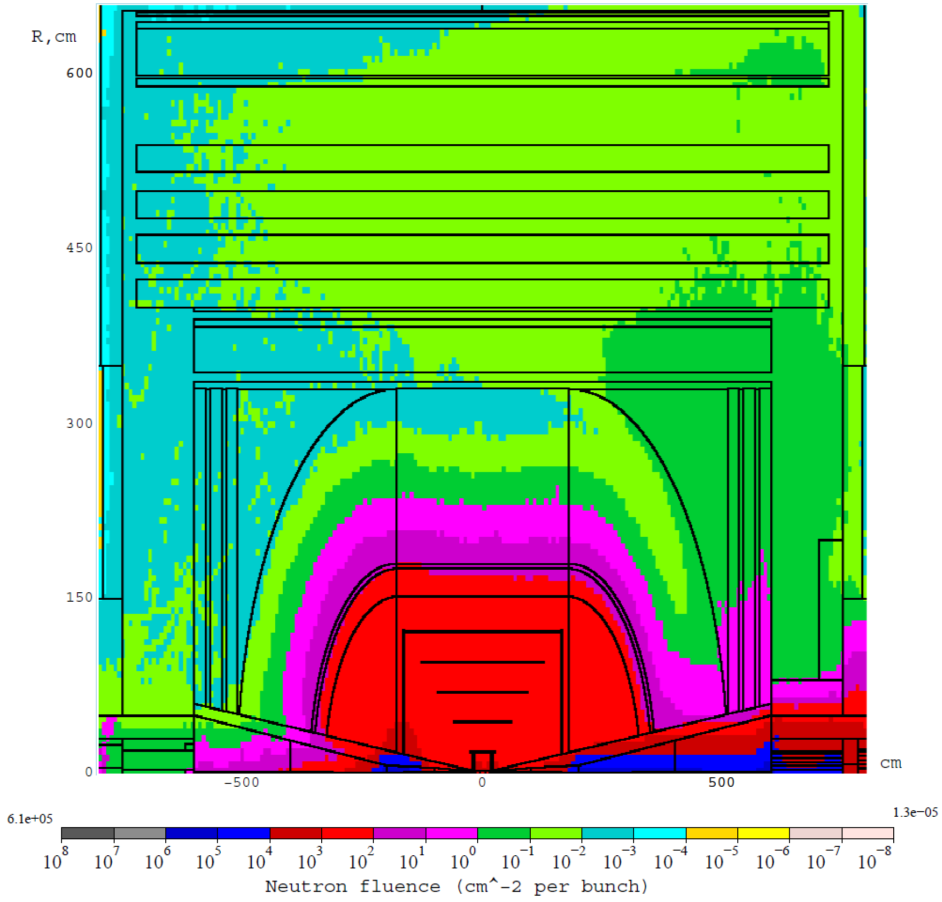


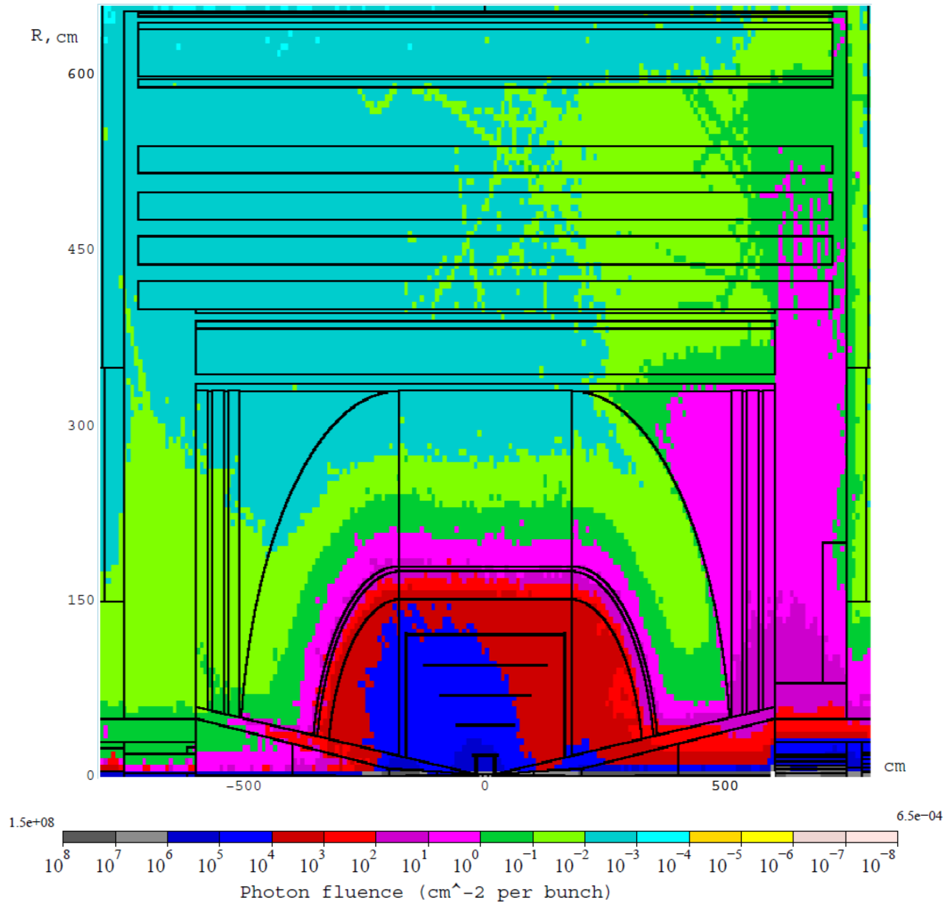
Muon and Charged Hadron Fluence



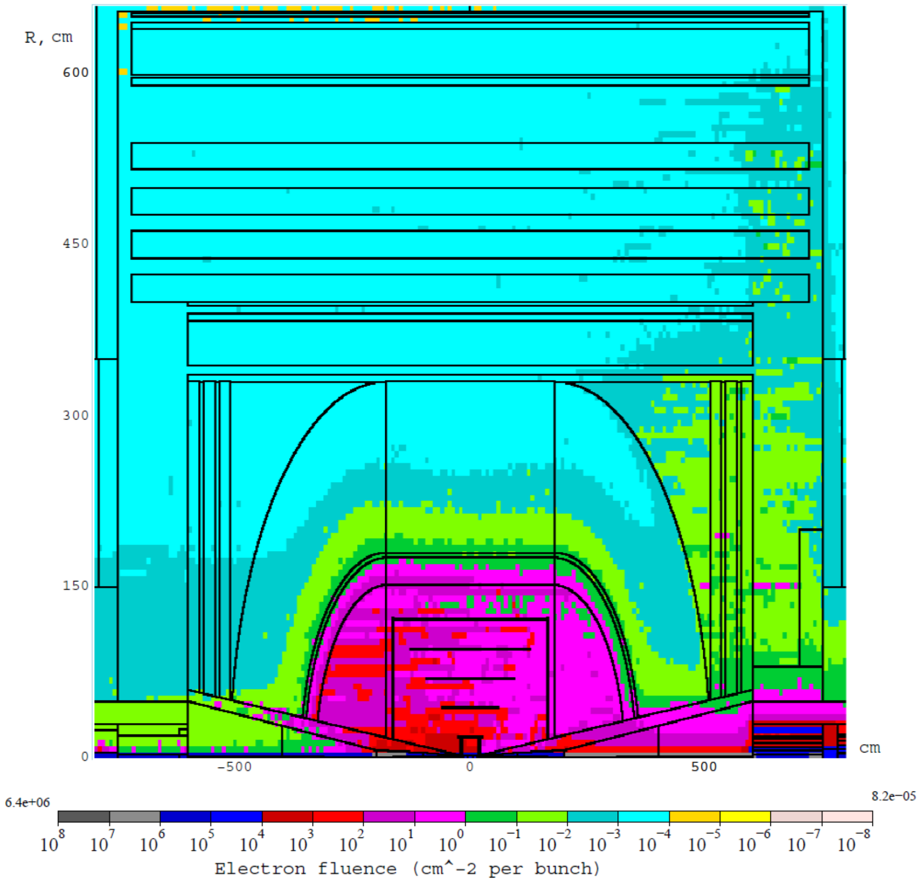


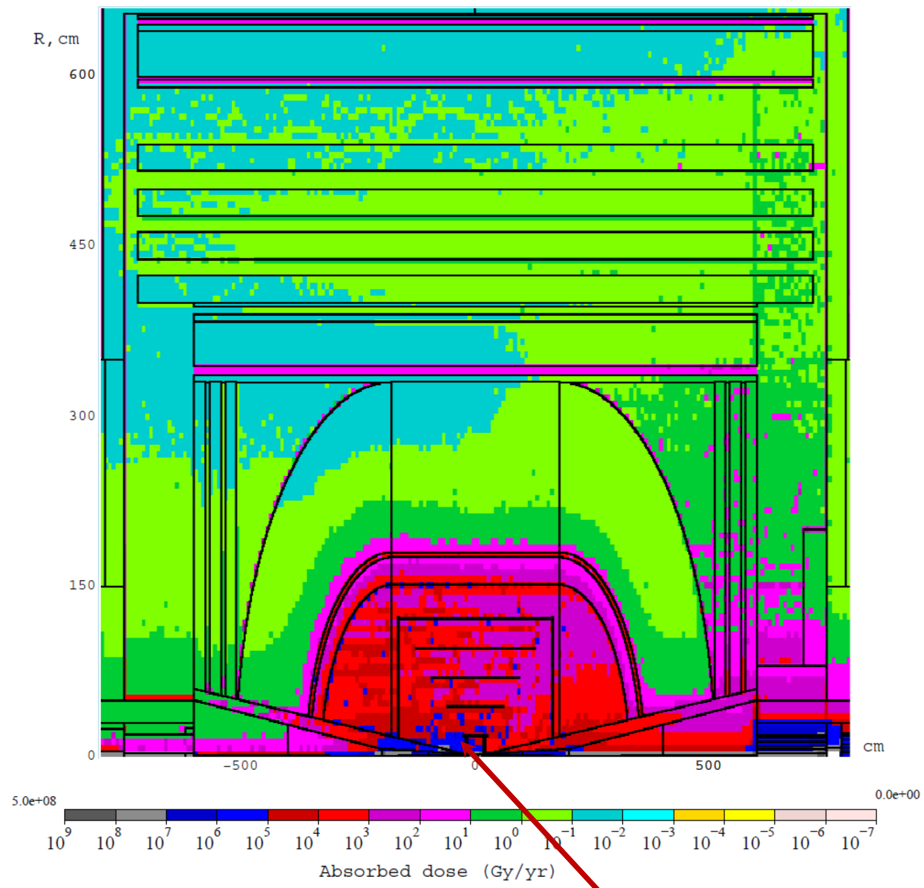
Neutron and Photon Fluence





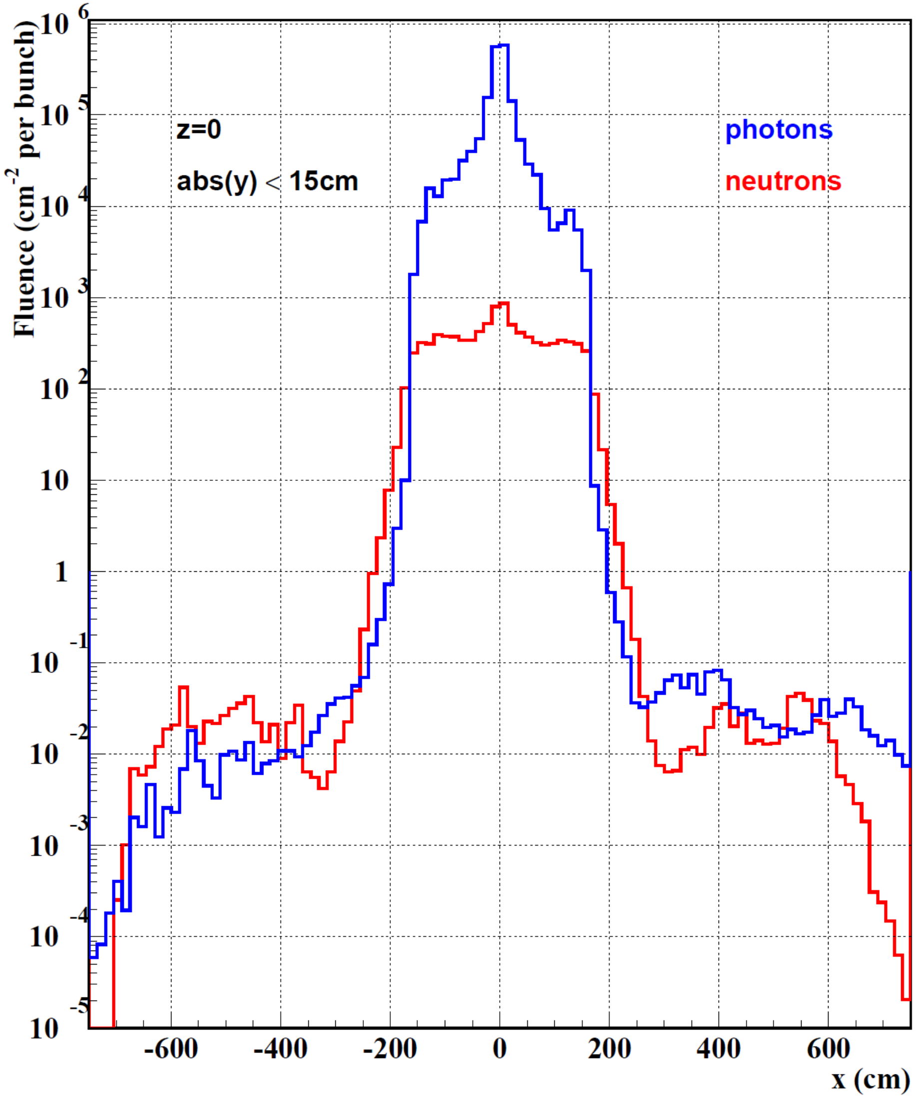
Electron Fluence and Total Dose per Year

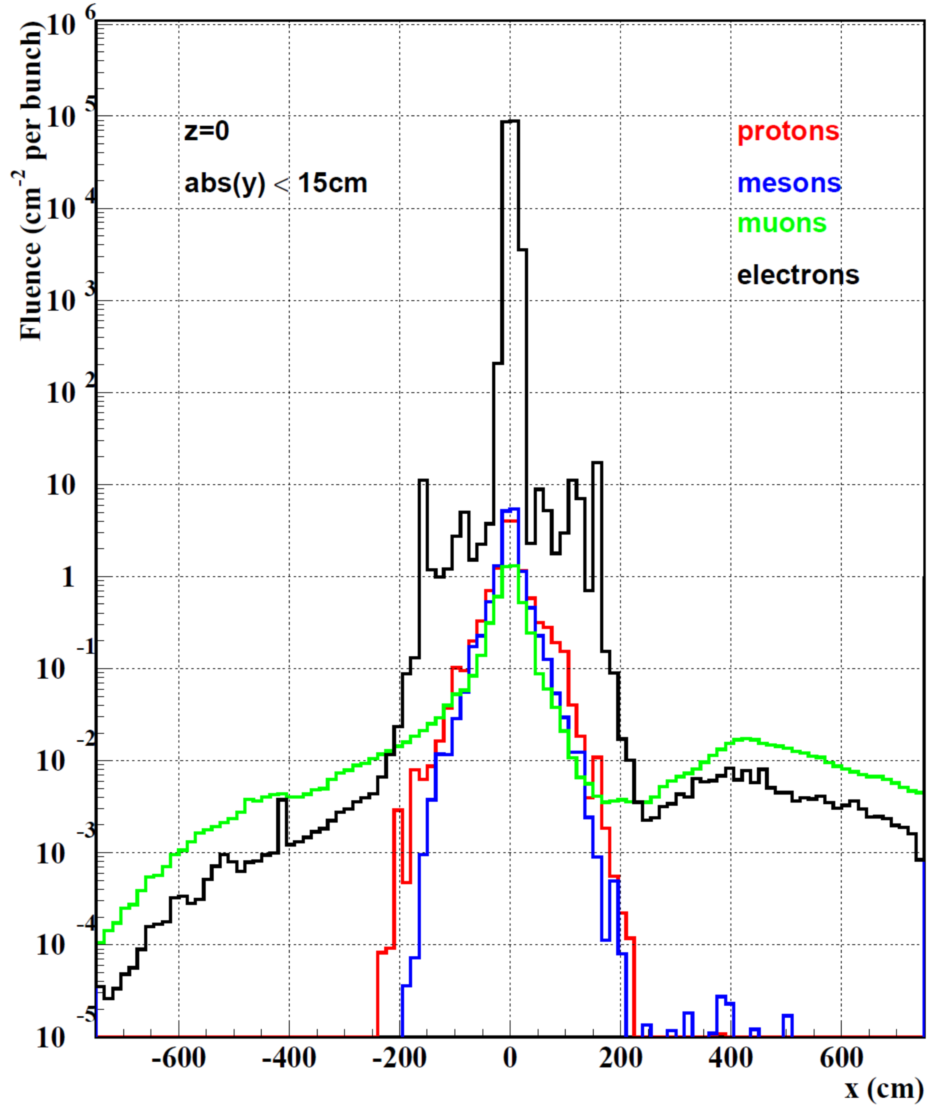




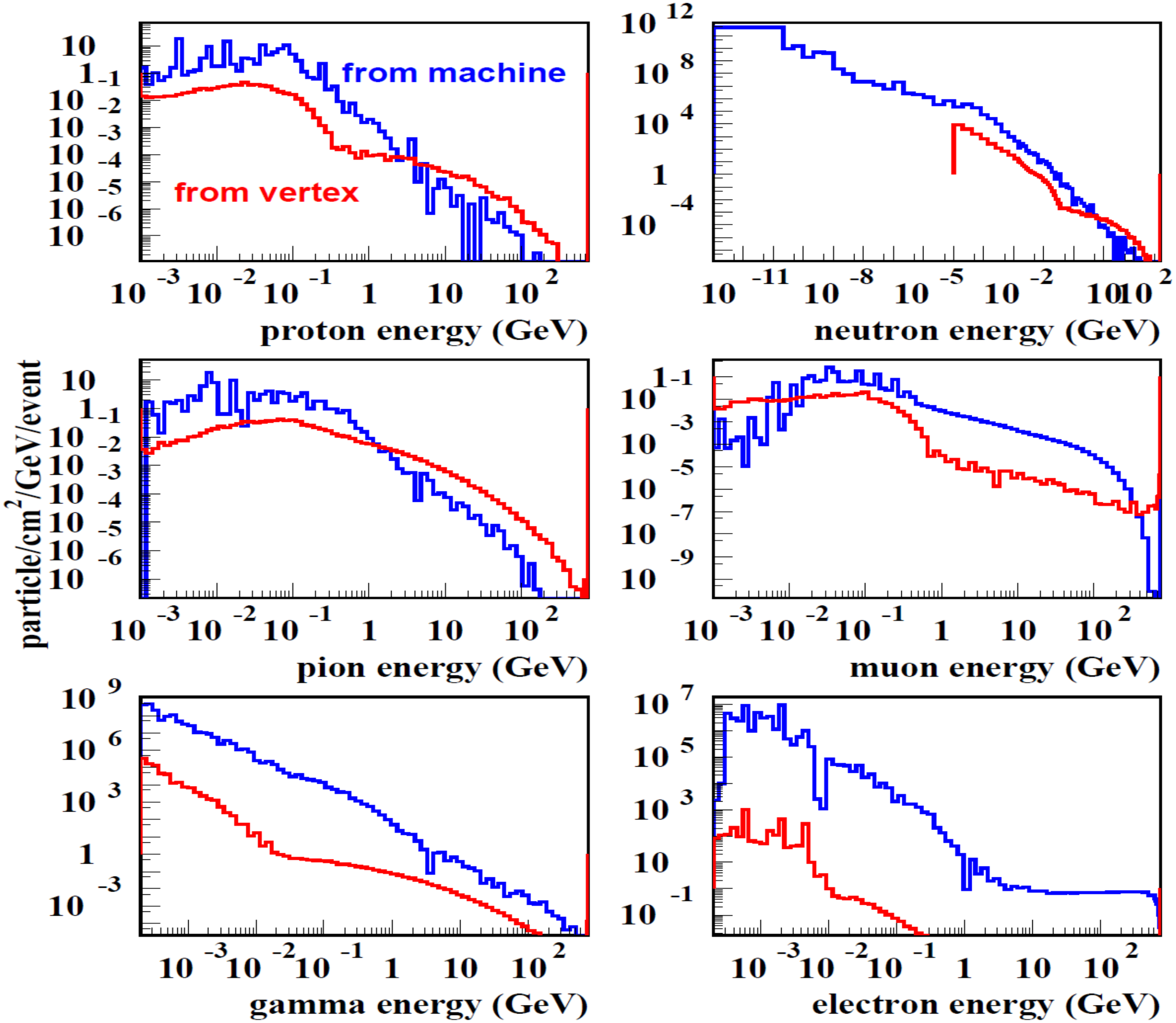
~1 MGy/yr for 2 beams

Particle Fluence in Horizontal Plane at z=0



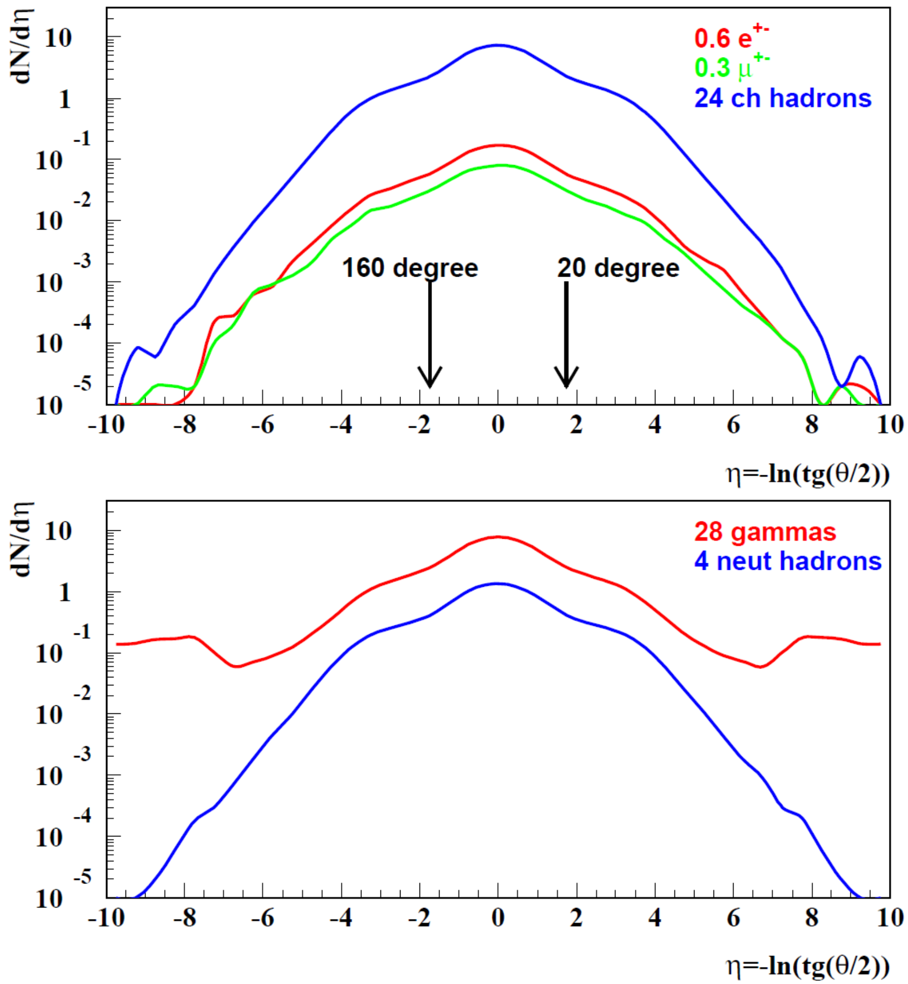


Machine vs Vertex Backgrounds in Tracker

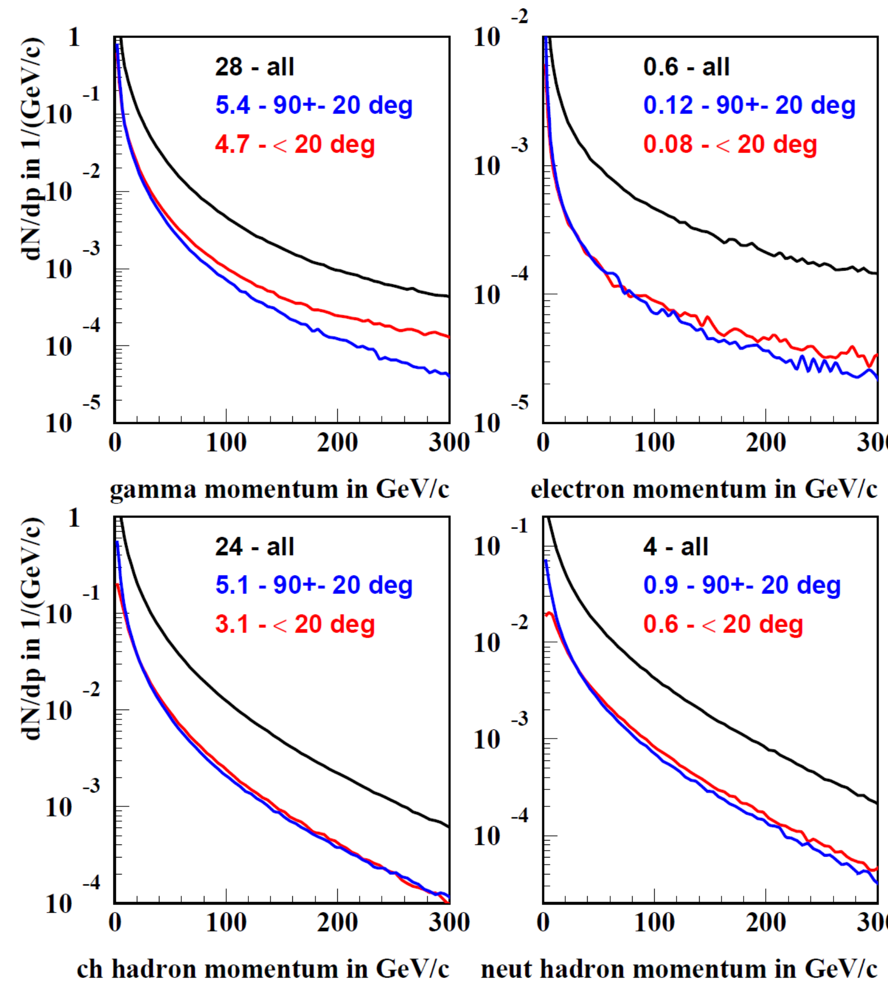


Energy spectra in tracker (+-46x46x5cm3)

Rapidity and Momentum Spectra from $\mu^+\mu^-$ Collision



$\mu^+\mu^- \to \gamma^*/Z^0$ at 1500 GeV (1.34 pb)



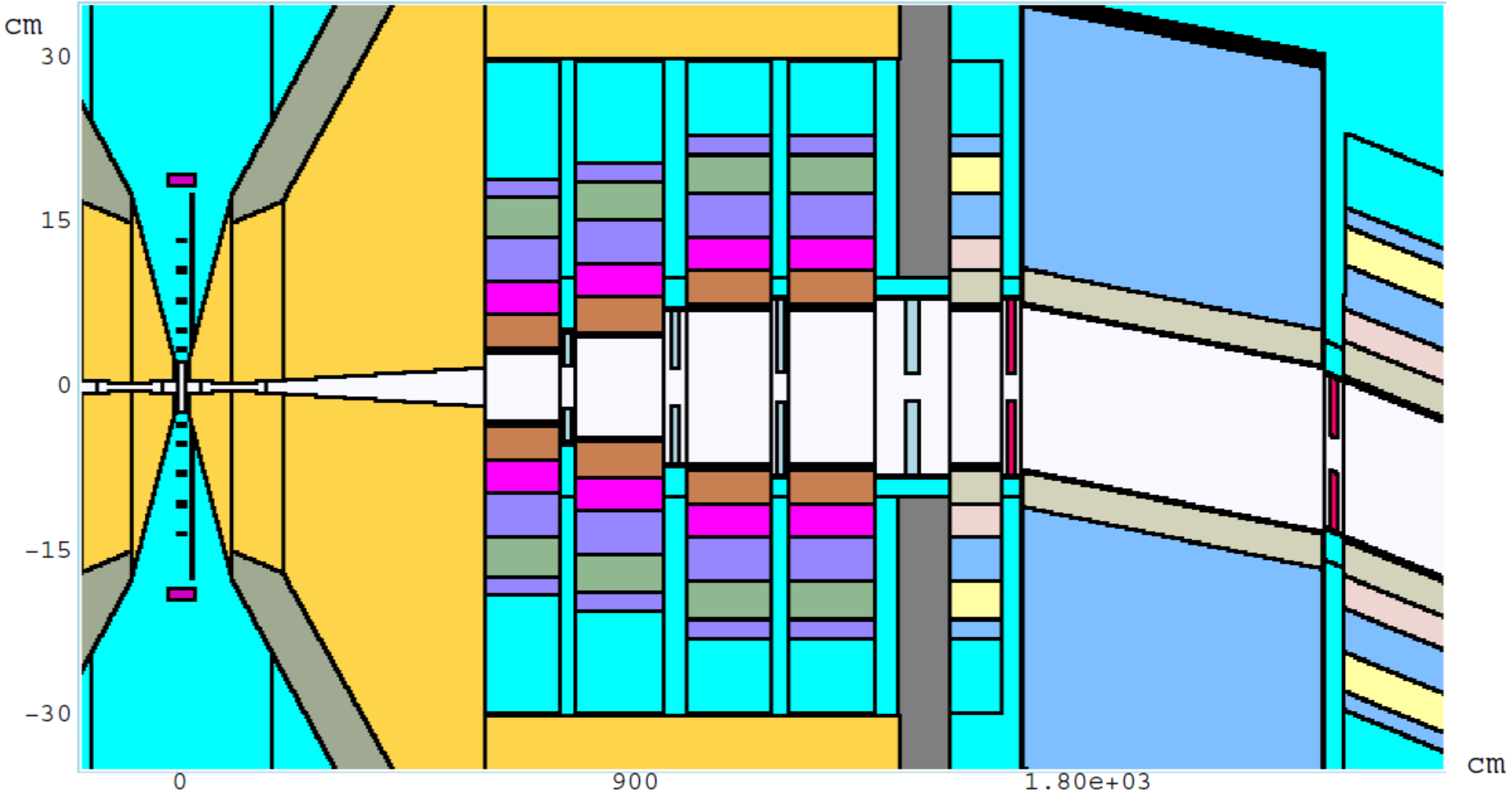
$\mu^+\mu^- \to \gamma^*/Z^0$ at 1500 GeV (1.34 pb)

PYTHIA calculations

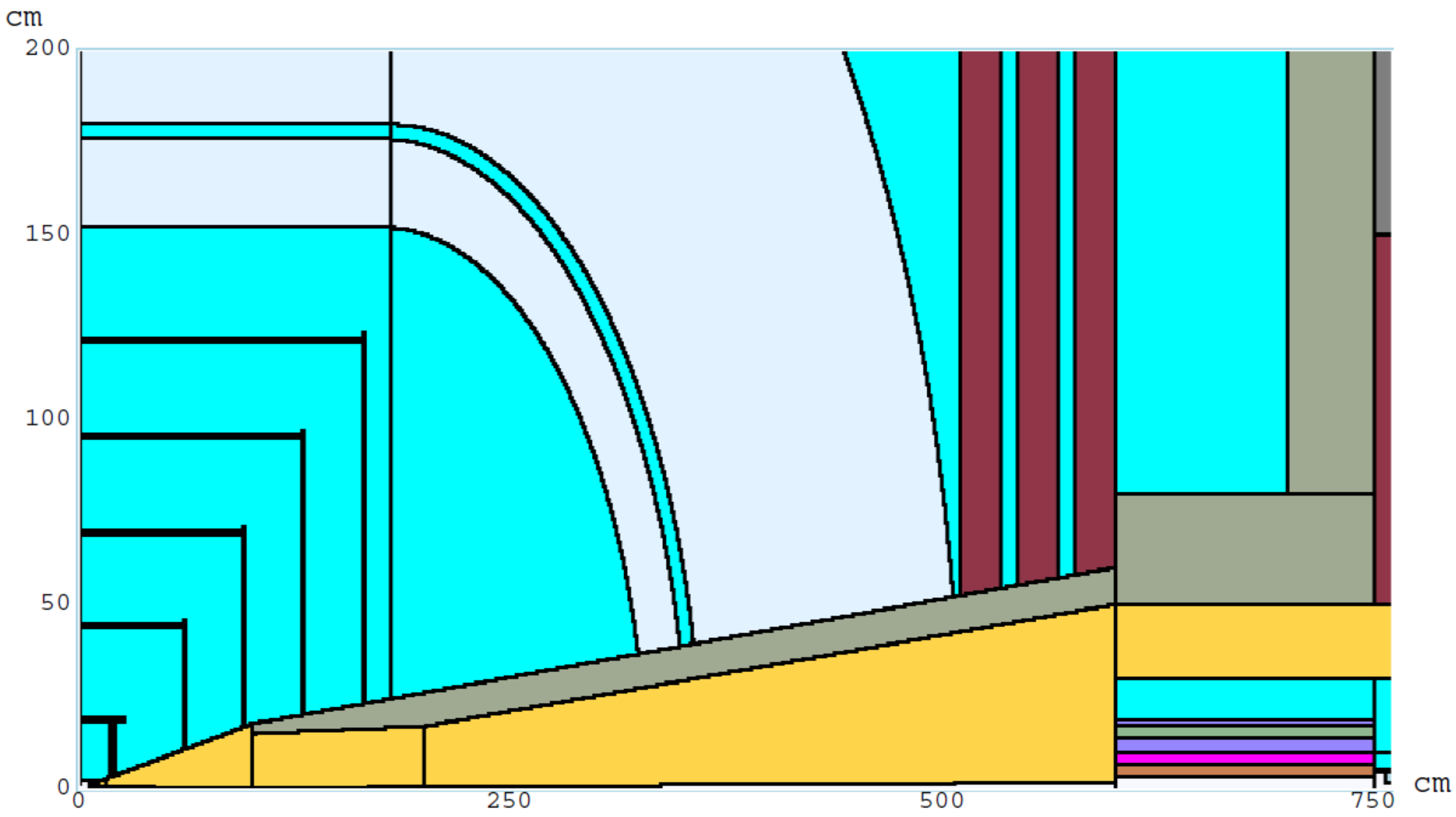
MARS15 Modeling (January 2010)

- Updated IR lattice with magnet interconnect constraints fulfilled and 5-sigma tungsten masks between quads.
- Further refined geometry of MDI and 4th concept ILC detector with B_z=3.5 T, with shielding and BCH_2 liners wherever needed.
- Tungsten nozzle starting at ±6cm from IP with R=1 cm at this z, BCH_2 shell (re-optimized). Variation of its outer angle (6, 10, 15 and 20 degrees). Optimization of its opening shape.
- 750-GeV bunch of 2×10^{12} μ^- approaching IP is forced to decay at -10 to 200 m at 4.28×10^5 per meter rate. To speed up calculations, some optimizations were done with z_{max}=35m rather than 200 m.

MARS15 MDI Model (January 2010)

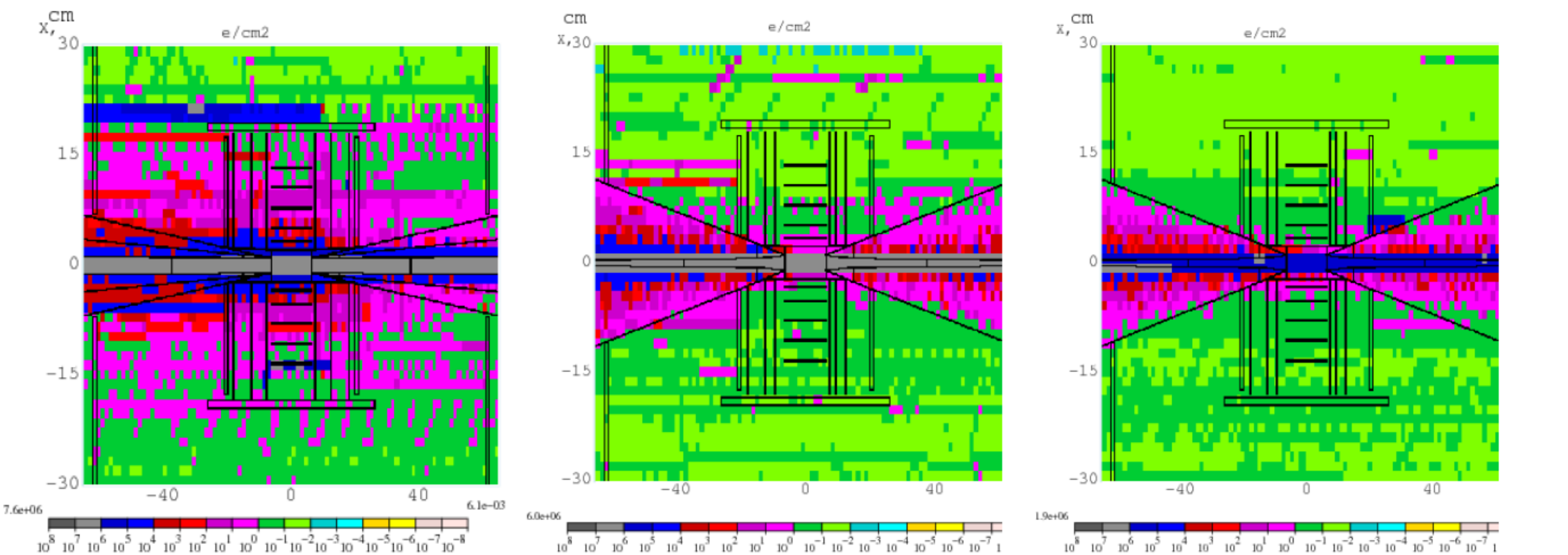


MARS15 MDI Model (January 2010)



Electron Flux

At CL and r=5cm: **1** **~1/500** **~1/100**



Left: Initial cone configuration (6°, 5σ inner radius up to 2m from IP), as reported at the November workshop at FNAL

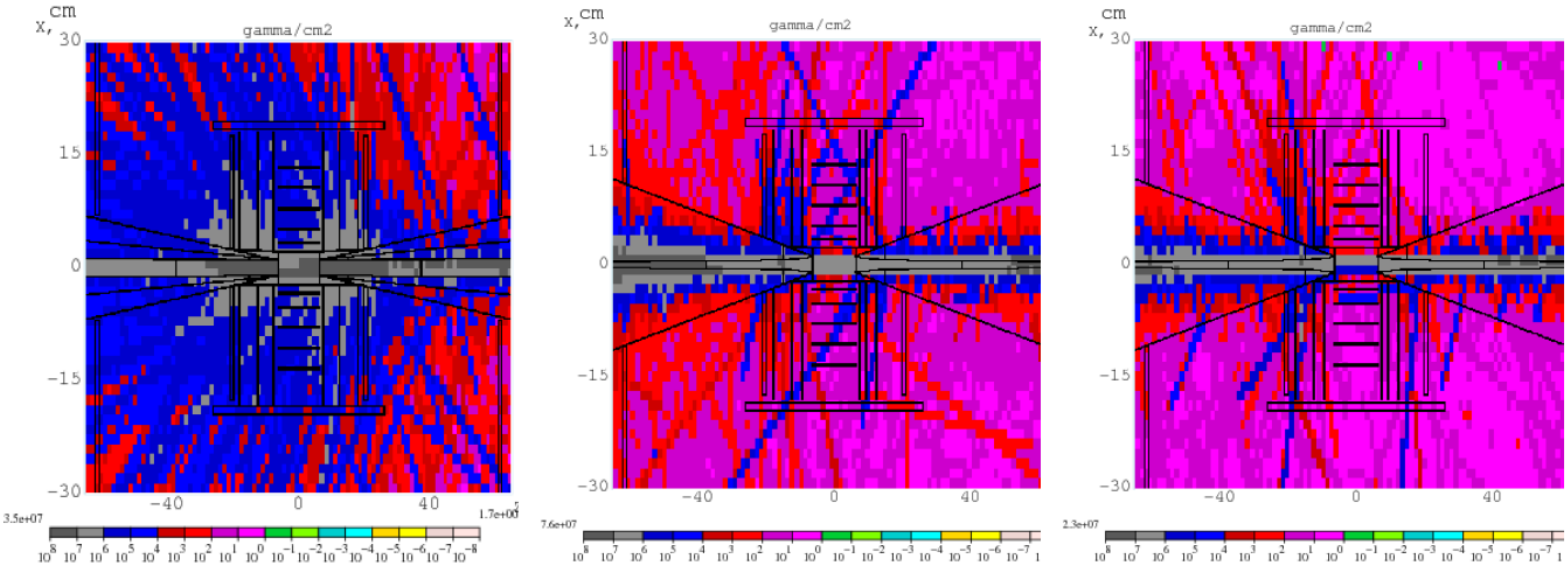
Central: Cone angle increased to 10 °, 5σ inner radius up to 1m from IP, 5σ masks inserted between FF quads

Right: Same, plus FF quads displaced by 1/10 of the aperture

z_{max}=75 m

Photon Flux

At CL and r=5cm: 1 ~1/20 ~1/1000



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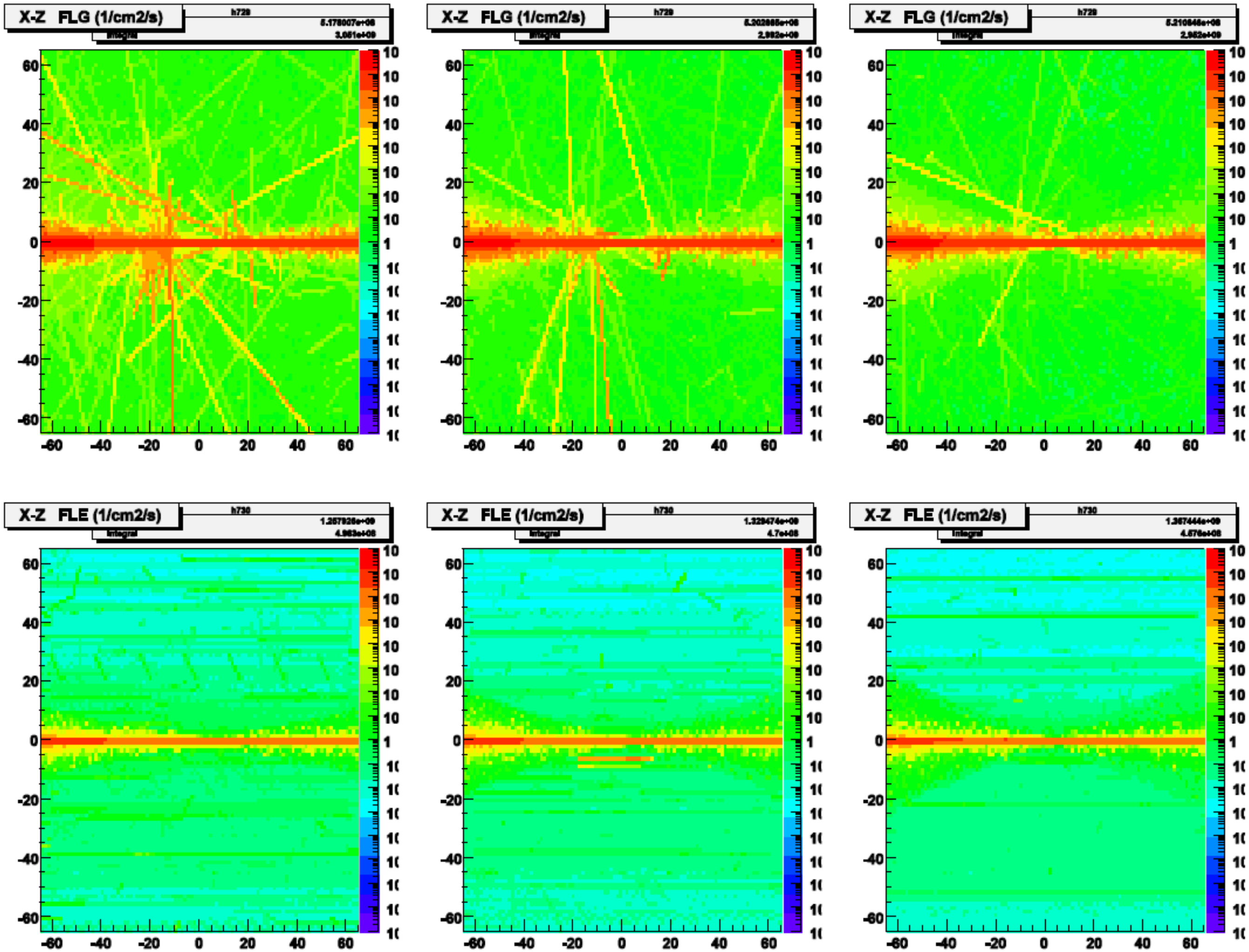
Right: Same, plus FF quads displaced by 1/10 of the aperture

z_{max}=75 m

Cone Outer Angle: 10°(L), 15°(C), 20°(R),

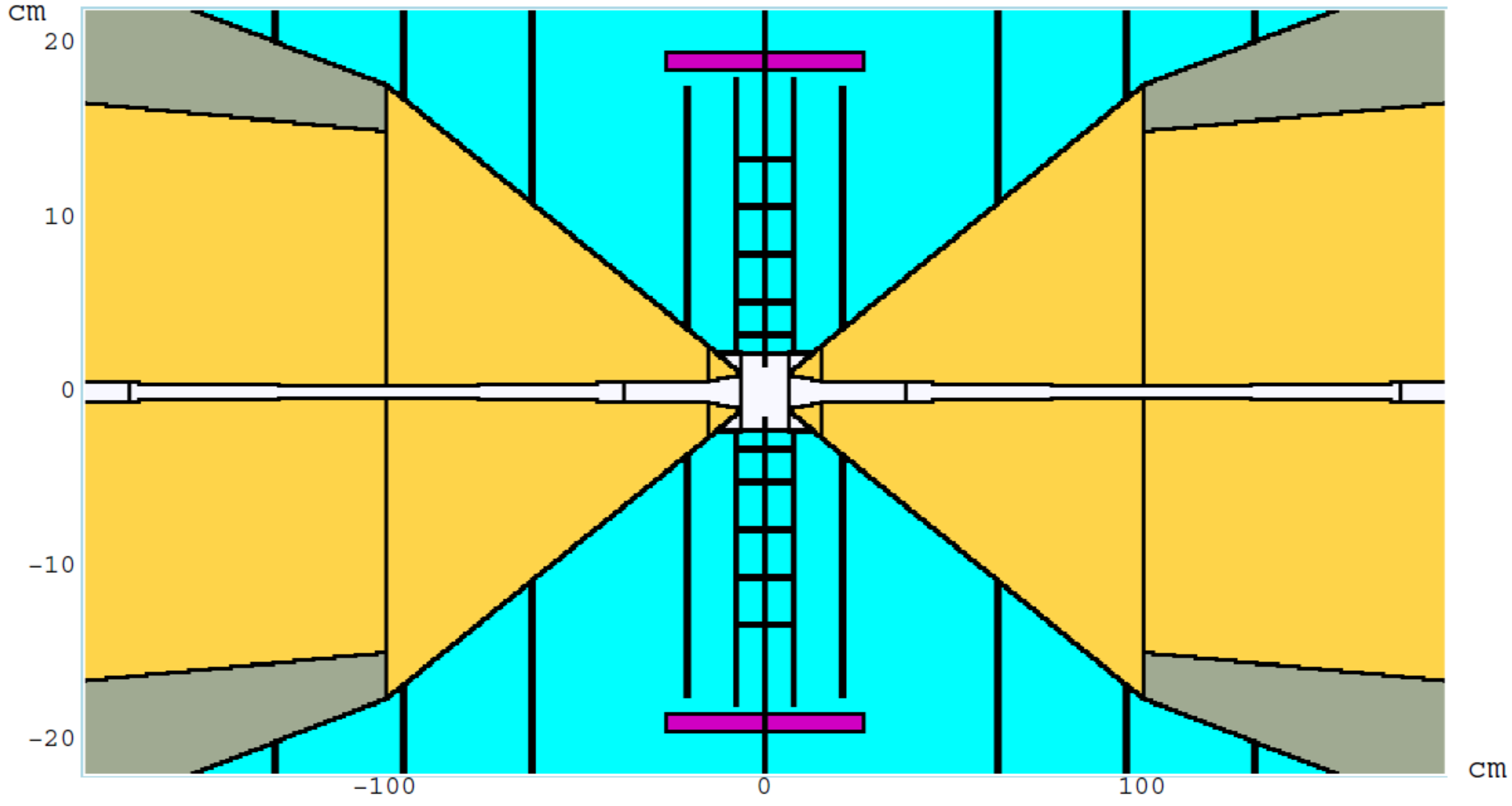


Photons

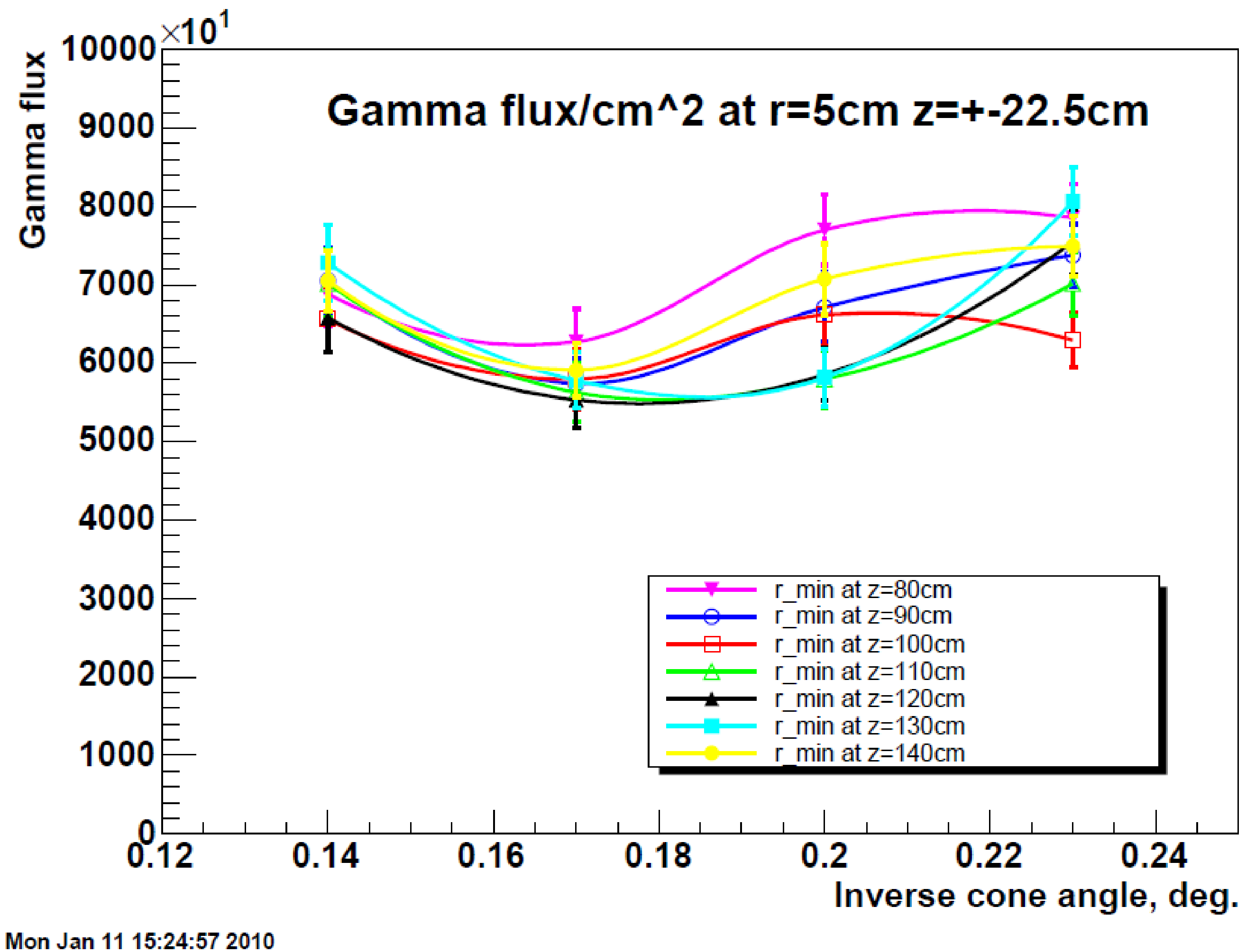
Electrons

z_{max}=75 m

MARS15 MDI Model: Cone Optimization



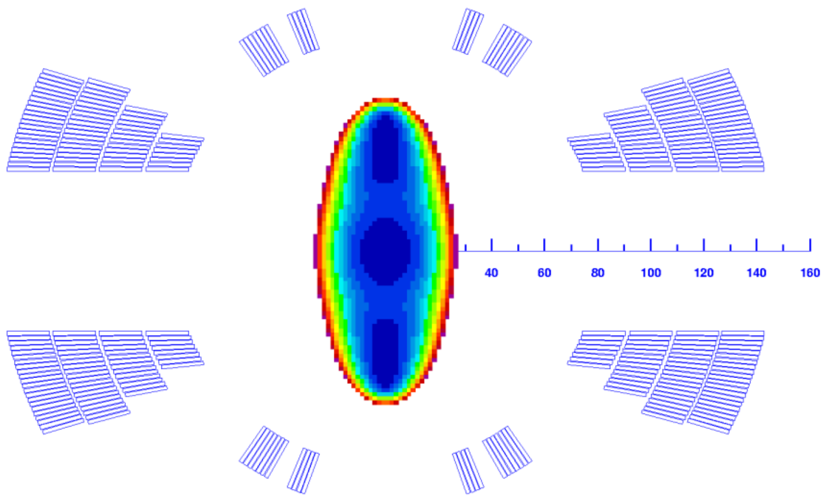
Inner Cone Shape Optimization

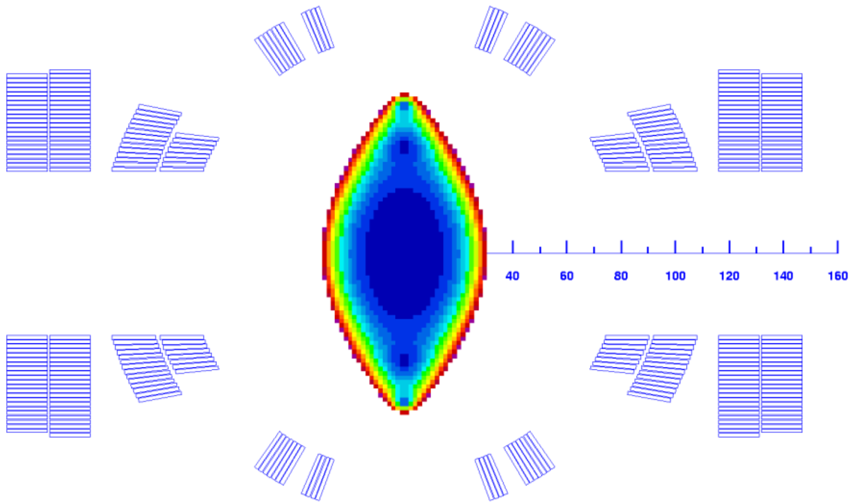


Optimum:
z~120 cm
with r=3.6mm
at this z.
1/10-1/20 of
November results

z_{max}=35 m

IR BE1 Open-Midplane Dipole (V.V. Kashikhin)





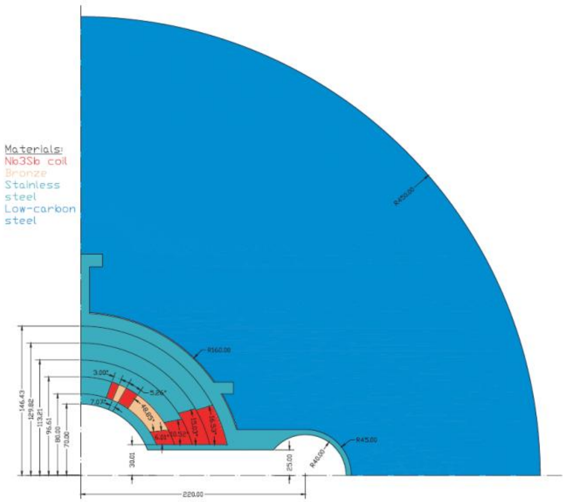
- One of the most challenging magnets in the list: large midplane gap and unusual aperture requirements
- Same concept as for the ring dipole, but field quality optimized for the vertically elongated beam
- Two double-shells or shell/block hybrid
- B_{op} ~ 8T with ~22% margin at 4.5K in either case.
- Midplane gap:

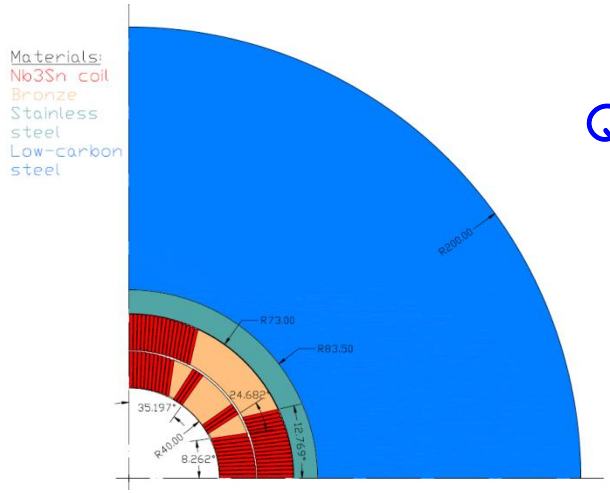
  Coil-coil – 60mm

  Clear – 50mm

IR Magnets

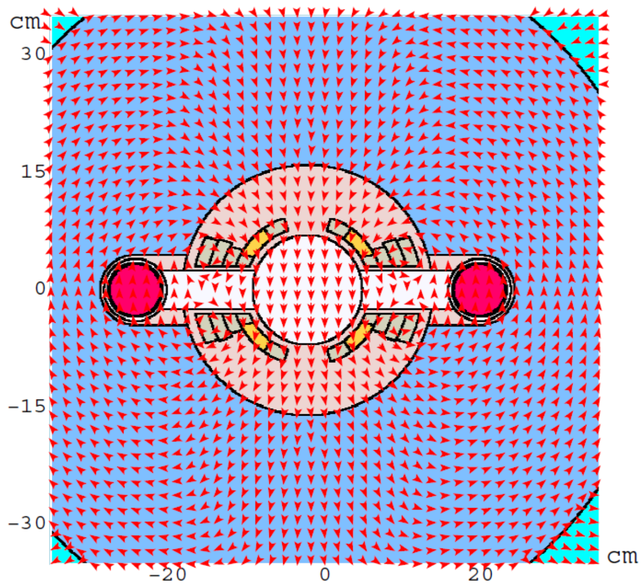
BE1: VK

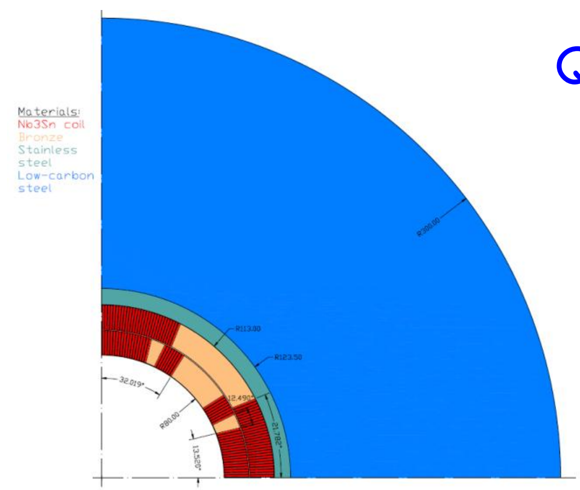




Q1: ID 80mm,
G=250 T/m

BE1: MARS





Q3: ID 160mm,
G=130 T/m

FNAL-INFN Task Force

Proposal of December 15, 2009, for a Task Force Simulation Group on studies for the feasibility of a high-energy physics experiment at a muon collider. Two-year 3-phase working plan on software development (MARS15 and ILCroot), and detector and MDI simulations.

MDI Issues and Work to Do (1)

1. Dealing with 0.5-1 kW/m loss rate in magnets (dynamic heat load and quench stability).

2. ~10 T dipoles: open midplane versus conventional cosθ (splitted in ~3m long pieces with masks in between and modest high-Z liners). Put significant effort into open mid-plane dipole designs to get field quality, handle the forces and enclose the beam dumps so that radiation is controlled in the tunnel.

3. Alternative technologies for short IR quads: permanent high-gradient quads very close to IP, holmium/gadolinium liners in quads, novel adhesive-free approach. Explore higher gradient quadrupoles and determine if a lower beta star is feasible. If this is possible, evaluate whether to use the gain to raise the luminosity or reduce N raise f and thus reduce the detector background.

4. Add more realistic geometry and magnetic field maps to MARS model.

MDI Issues and Work to Do (2)

5. Interconnect regions: 40-50 cm needed, seems OK for optics, backgrounds and neutrino radiation for 750-GeV muon beams; need to keep them as short as possible with energy going up.

6. Design a ring for 3 TeV and compare the background problems with 1.5 TeV.

7. Explore if short 20-30 T solenoid(s) from the last bend to the IP (with gaps for the quadrupoles) would help backgrounds.

8. For each design, determine how much shielding is needed inside the final quadrupoles.

MDI Issues and Work to Do (3)

9. Continue the optimization of detector background, balancing advantages of smaller nozzle angle vs effects of the greater background if it has a smaller angle, not sacrificing physics; consider its instrumentation (Lumical and other ILC experience).

10. Investigate if such an optimal cone confines incoherent pairs with the detector 3.5-T field.

11. Establish an MDI Task Force with a very tight connection between accelerator, magnet and detector groups.

12. Model detector response to physics signal in presence of IP and machine backgrounds. To first order, the backgrounds will drive critical parameters of the MC detector design, not the physics.

13. Revisit beam scraping schemes for 0.75 and 1.5-TeV muon beams.